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(54) Apparatus for determining temperature

(57) An apparatus for determining temperature in an electrical equipment wherein estimates of the temperatures at predetermined locations in the equipment are obtained from samples of the voltage and current supplied to the equipment using a thermal model of the equipment comprising a number of nodes (27) interconnected by paths of predetermined thermal conductivity (29), each node having a predetermined thermal capacity and/or a predetermined thermal generating capability dependent on the sample values of voltage and current.

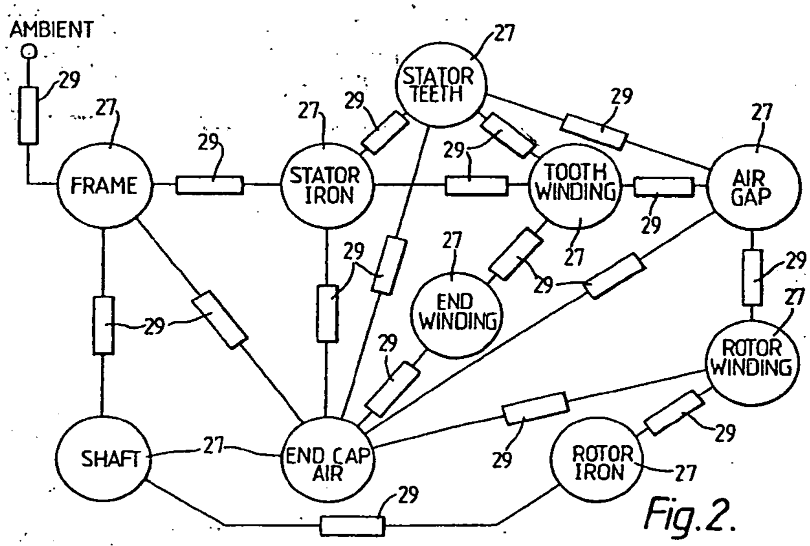

Fig.2.

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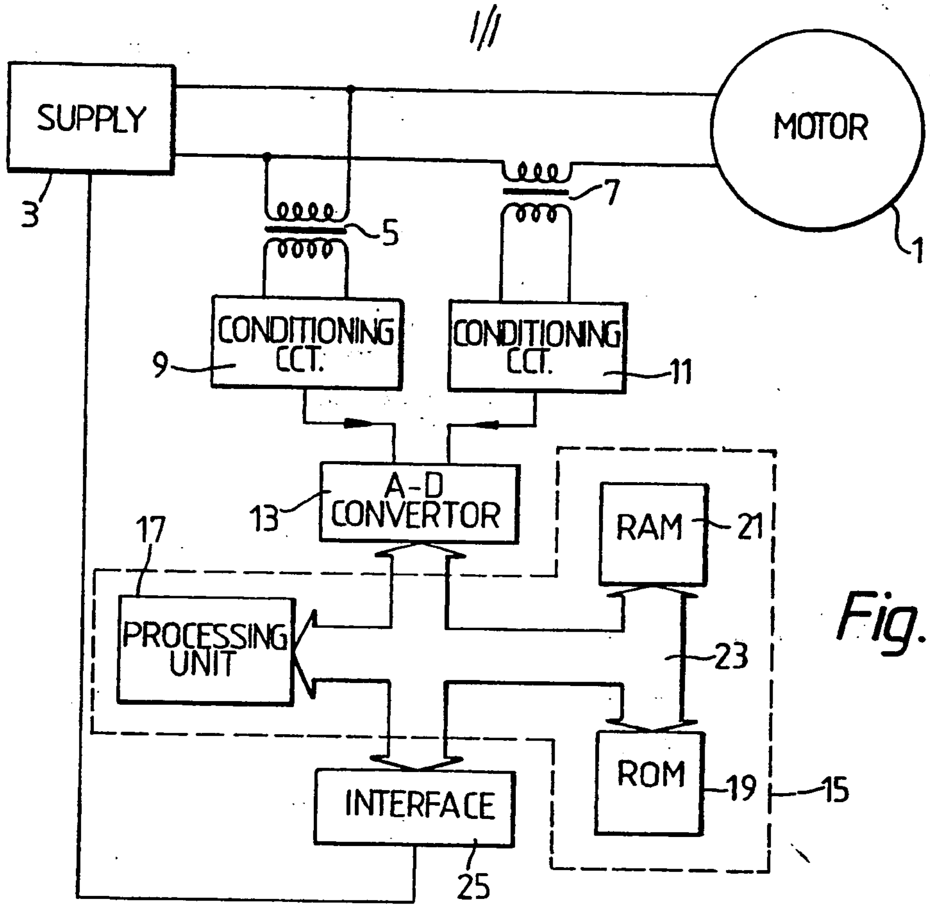

Fig. 1.

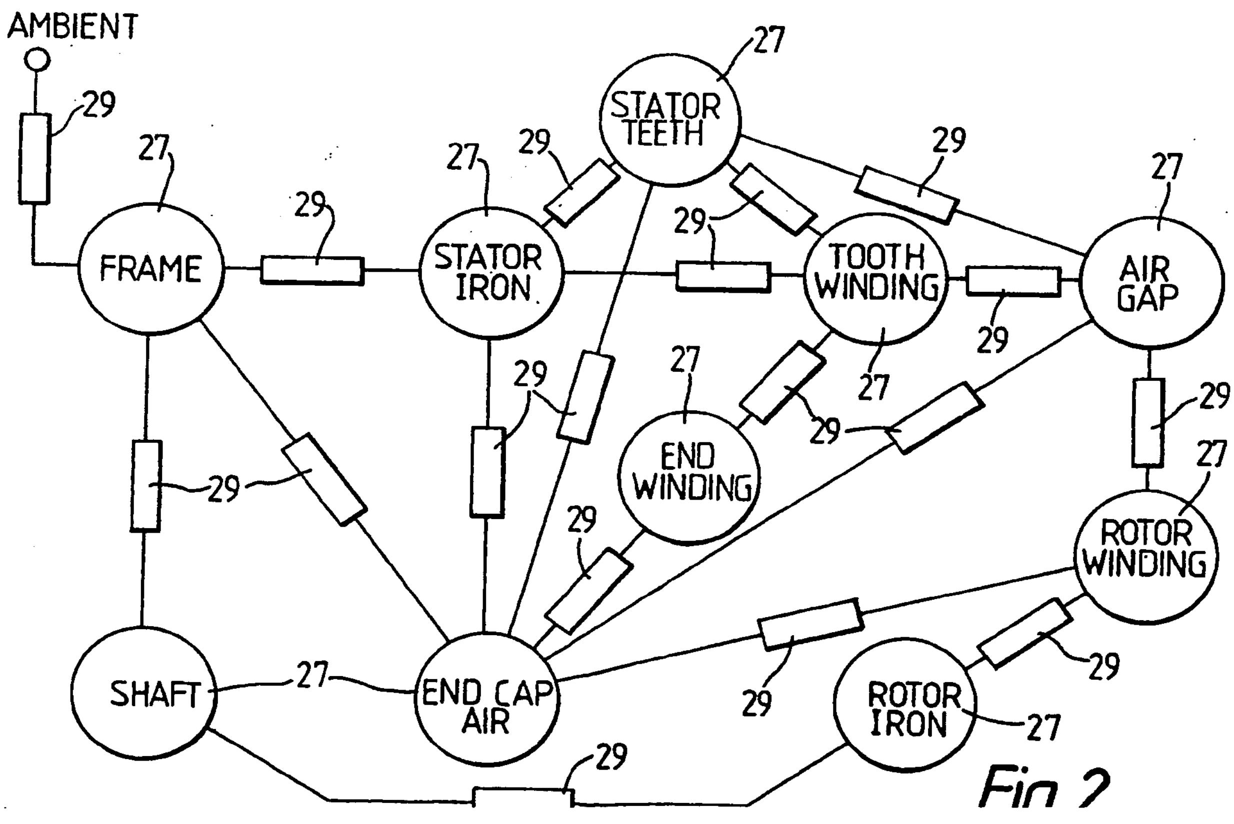

Fig. 2

SPECIFICATION

Apparatus for determining temperature in electrical equipment

This invention relates to apparatus for determining temperature in electrical equipment.

The most direct method of determining temperature in electrical equipment is by the insertion of electronic temperature detectors, such as thermocouples, thermistors or platinum resistance elements, at suitable places in the equipment, and monitoring the outputs of the detectors. This approach has the disadvantage that it is difficult to locate the detectors in the places in the equipment which are of most interest, and that the provision of accurate detection and monitoring circuits and the associated leads is difficult and costly.

An alternative approach is to provide an electric circuit which simiultes the thermal behaviour of the equipment. Known such arrangements range from a simple bi-metal element arranged to be heated by the current supplied to the equipment to complex analogue circuits in which different sections of the thermal circuit of the equipment are represented by resistor-capacitor combinations and the heat generated in the equipment is represented by current or voltage sources interconnected by the resistor-capacitor combinations. However, to obtain satisfactory results from such an arrangement a very complex analogue circuit is required to which additional circuitry has to be added to compensate for long term non-linearities in the resistor-capacitor combinations.

It is an object of the present invention to provide an apparatus for determining temperature in electrical equipment which overcomes the above difficulties.

According to the present invention an apparatus for determining temperature in an electrical equipment comprises: means for periodically sampling voltage and current conditions of the equipment; and digital computer means responsive to the sampled values of current and voltage to estimate the temperature of at least one predetermined location in the equipment by calculations based on a thermal model of the equipment comprising a number of nodes interconnected by paths of predetermined thermal conductivity, each node having a predetermined thermal generating capability dependent on the sampled values of current and voltage and/or a predetermined thermal capacity.

In a preferred arrangement in accordance with the invention the computer means if further arranged to estimate the future temperature at said location in the equipment.

It will be appreciated that an apparatus in accordance with the invention will normally be arranged to estimate the temperature at two or more locations in the equipment simultaneously.

An apparatus in accordance with the invention is suitably associated with control means whereby control of the equipment operation may be effected in response to the temperature of the equipment as estimated by the computer means.

One apparatus in accordance with the invention will now be described by way of example with reference to the accompanying drawings in which:-

Figure 1 is a block schematic diagram of the apparatus; and

Figure 2 illustrates a thermal model of a machine whose temperature is determined by the apparatus.

Referring to Figure 1, the apparatus is arranged to determine the temperature at various locations in a single phase alternating current motor 1 energised from a supply 3.

The apparatus includes voltage and current transformers 5 and 7 which produce reduced scale replicas of the voltage and current supplied to the motor 1. The output of the transformers 5 and 7 are passed via respective conditioning circuits 9 and 11 to an analogue-to-digital convertor circuit 13.

The apparatus further includes computer means in the form of a microprocessor 15 comprising a processing unit 17 interconnected with read-only memory (ROM) 19 and a random access memory (RAM) 21 via a data bus 23 in conventional manner.

In operation, under control of a program stored in the RAM 21 the processor unit 17 periodically samples the digital signals at the output of the converter 13 which are representative of the values of the supply voltage and current. Using the samples values, the processor then performs calculations, as further described below to obtain periodically an estimation of the current temperature at one or more locations in the motor.

It will be appreciated that the temperature estimations also require a knowledge of ambient temperature which may be assumed constant and stored in the RAM 21 or may be measured by an electrical thermometer (not shown).

The estimated values of motor temperature are outputted for use in any desired manner via an interface 25.

The estimated values may, for example, simply be used to operate a display device (not shown) to provide a visual display of the estimated temperatures.

Alternatively, the estimated values may be used to control the operation of the motor, for example, so as to cut off the electric supply to the motor if an estimated temperature exceeds a predetermined maximum permitted value.

The desired control function may be effected under control of the microprocessor, as indicated in Figure 1. Alternatively the desired control function may be effected under control of a dedicated machine controller (not shown) to which the interface 25 supplies signals representative of estimated temperature.

In addition to estimating current temperature, the microprocessor 15 may also be arranged to predict future temperature on the basis of an assumed pattern of future motor loading.

Calculation of temperature by the microprocessor 15 is based on a thermal model of the motor of the form illustrated in Figure 2.

The thermal model comprises a number of nodes 27 each of which is representative of a different component of the motor structure, for eample, the motor frame, the stator iron, etc., as shown in Figure 2. Each node 27 is assigned a predetermined thermal capacity and a predetermined thermal generating capability, the latter depending also on the voltage and current supplied to the motor. The modes 27 are interconnected by paths 29 of predetermined thermal conductivity.

The differential equations that describe the thermal operation of the model can be written in the matrix form

$$C\frac{d\theta}{dt} = A\theta + G \qquad (1)$$

where
θ represents the nodal temperture matrix
C represents the thermal capacitance matrix
A represents the thermal conductance matrix and
G represents the nodal heat generation matrix

The mathematical solution of equation (1) is:

$$\theta(t) = e^{A't}\,\theta\,(o) + e^{A't}\int_o^t e^{-A't}\,G'dt \qquad (2)$$

where
$A' = C^{-1}A$;
$G' = C^{-1}G$; and
θ (o) is the temperature at time t = 0 (i.e. the initial temperature).

Assuming heat generation remains constant over a period T, equation (2) can be rewritten to give current temperature by step by step calculations, as follows:

$$\theta\,(n\,T) = e^{A'T}\theta\,[(n-1)\,T] + A'^{-1}(e^{A'T}-1)\,G' \qquad (3)$$

where
$\theta[(n-1)\,T]$ represents the nodal temperature matrix before step *n*
$\theta(n\,T)$ represents the nodal temperature matrix after step *n*; and
G' represents the nodal heat generation matrix over period T

G' is a linear matrix function of the machine voltage and current during the nth period, that is

$$G' = Ri^2 + Yv^2 \qquad (4)$$

where
i represents machine current;
v represents machine voltage; and
R and Y are constant matrices

Also the constant matrices $e^{A'T}$ and $A'^{-1}(e^{A'T}-1)$ in equation (3) can be calculated for a given step period T using eigen value/vector techniques.

It will be appreciated that in the thermal model shown in Figure 2 some of the nodes, e.g. the air gap node, may be assumed to have zero thermal capacitance. If desired, such nodes may be eliminated using standard matrix operations and the order of the matrix equation correspondingly reduced to simplify the calculations carried out by the microprocessor.

In one embodiment of the invention in which temperature calculation was based on a fifteen node thermal model reduced to eight nodes as described above, motor voltage and current were sampled at one second intervals and the microprocessor performed the matrix calculations (3) and (4) to estimate current machine temperature within 0.1 second. The remaining 0.9 second could then be used to predict future temperature.

It will be understood that whilst the apparatus described above the way of example is utilised to determine temperature in an electric motor, an apparatus in accordance with the invention may be used to determine temperature in any electric equipment which can be thermally modelled.

CLAIMS

1. An apparatus for determining temperature in an electrical equipment comprising means for periodically sampling voltage and current conditions of the equipment; and digital computer means responsive to the sampled values of current and voltage to estimate the temperature of at least one predetermined location in the equipment by calculations based on a thermal model of the equipment comprising a number of nodes interconnected by paths of predetermined thermal conductivity, each node having a predetermined thermal generating capability dependent on the sampled values of current and voltage and/or a predetermined thermal capacity.

2. An apparatus according to Claim 1 wherein said computer means is further arranged to predict the future temperature at said location.

3. An apparatus according to Claim 1 or Claim 2 wherein said computer means is arranged to estimate the temperature at two or more locations in the equipment simultaneously.

4. An apparatus according to any one of the preceding claims associated with control means whereby control of the equipment operation is effected in response to the temperature of the equipment as estimated by said computer means.

5. An apparatus according to any one of the preceding claims wherein said equipment is an electric motor and said voltage and current conditions are the voltage and current supplied to the motor.

6. An apparatus for determining temperature in an electrical equipment substantially as hereinbefore described with reference to the accompanying drawings.

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